DEPARTMENT OF THE INTERIOR
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GEYSERS OF THE YELLOWSTONE NATIONAL PARK

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THE NATIONAL PARKS AT A GLANCE.

[Number, 19; total area, 10,859 square miles.]

National parks in order of creation.	Location.	Area in square miles.	Distinctive characteristics.
Hot Springs........ 1832	Middle Arkansas......	1½	46 hot springs possessing curative properties—Many hotels and boarding houses—20 bathhouses under public control.
Yellowstone........ 1872	Northwestern Wyoming.	3,348	More geysers than in all rest of world together—Boiling springs—Mud volcanoes—Petrified forests—Grand Canyon of the Yellowstone, remarkable for gorgeous coloring—Large lakes—Many large streams and waterfalls—Vast wilderness, greatest wild bird and animal preserve in world—Exceptional trout fishing.
Sequoia............ 1890	Middle eastern California.	252	The Big Tree National Park—12,000 sequoia trees over 10 feet in diameter, some 25 to 36 feet in diameter—Towering mountain ranges—Startling precipices—Cave of considerable size.
Yosemite........... 1890	Middle eastern California.	1,125	Valley of world-famed beauty—Lofty cliffs—Romantic vistas—Many waterfalls of extraordinary height—3 groves of big trees—High Sierra—Waterwheel falls—Good trout fishing.
General Grant...... 1890	Middle eastern California.	4	Created to preserve the celebrated General Grant Tree, 35 feet in diameter—6 miles from Sequoia National Park.
Mount Rainier...... 1899	West central Washington.	324	Largest accessible single peak glacier system—28 glaciers, some of large size—48 square miles of glacier, 50 to 500 feet thick—Wonderful subalpine wild flower fields.
Crater Lake........ 1902	Southwestern Oregon.	249	Lake of extraordinary blue in crater of extinct volcano—Sides 1,000 feet high—Interesting lava formations—Fine fishing.
Wind Cave.......... 1903	South Dakota.........	17	Cavern having many miles of galleries and numerous chambers containing peculiar formations.
Platt.............. 1904	Southern Oklahoma...	1⅓	Many sulphur and other springs possessing medicinal value.
Sullys Hill........ 1904	North Dakota........	1⅛	Small park with woods, streams, and a lake—Is an important wild-animal preserve.
Mesa Verde......... 1906	Southwestern Colorado.	77	Most notable and best preserved prehistoric cliff dwellings in United States, if not in the world.
Glacier............ 1910	Northwestern Montana.	1,534	Rugged mountain region of unsurpassed Alpine character—250 glacier-fed lakes of romantic beauty—60 small glaciers—Precipices thousands of feet deep—Almost sensational scenery of marked individuality—Fine trout fishing.
Rocky Mountain.... 1915	North middle Colorado.	397½	Heart of the Rockies—Snowy range, peaks 11,000 to 14,250 feet altitude—Remarkable records of glacial period.
Hawaii............. 1916	Hawaii...............	118	Three separate areas—Kilauea and Mauna Loa on Hawaii; Haleakala on Maui.
Lassen Volcanic.... 1916	Northern California...	124	Only active volcano in United States proper—Lassen Peak 10,465 feet—Cinder Cone 6,879 feet—Hot springs—Mud geysers.
Mount McKinley... 1917	South central Alaska..	2,200	Highest mountain in North America—Rises higher above surrounding country than any other mountain in the world.
Grand Canyon...... 1919	North central Arizona.	958	The greatest example of erosion and the most sublime spectacle in the world.
Lafayette.......... 1919	Maine coast..........	8	The group of granite mountains upon Mount Desert Island.
Zion.............. 1919	Southwestern Utah...	120	Magnificent gorge (Zion Canyon), depth from 800 to 2,000 feet, with precipitous walls—Of great beauty and scenic interest.

GEYSERS OF THE YELLOWSTONE NATIONAL PARK.

By Walter Harvey Weed.[1]

GENERAL STATEMENT.

The hot-water fountains, called geysers, are natural wonders that are of general as well as scientific interest. The striking manifestation which they afford of the earth's internal heat, their great beauty, and novel surroundings make them indeed worthy of that widespread interest which they arouse, and it is in the hope of gratifying a general curiosity concerning these wonderful fountains that the present paper has been written.

At the outset of this inquiry into the nature and occurrence of these natural steam engines it is necessary to exactly define what is a geyser. Briefly, a geyser is a hot spring which intermittently ejects a column of boiling water and steam. Before attempting to present such a general account of the various geyser regions of the world as will enable the reader to follow the deductions derived from a study of the occurrence and the characteristics of geysers, it may be well to present a summary of the paper.

It is believed that the facts recorded in this article show:

First. That geysers occur only in volcanic regions and in acid volcanic rocks. In Iceland and New Zealand the volcanic fires are still active.

Second. Geysers occur only along lines of drainage, on shores of lakes or other situations where meteoric waters would naturally seek the surface.

Third. Geyser waters are meteoric waters which have not penetrated to great depths, but have been heated by ascending vapors.

Fourth. The supply of heat is derived from great masses of lava slowly cooling from a state of former incandescence, heating waters, which, descending to the hot rocks, ascend as highly heated vapors.

[1] Revised in 1921 by the National Park Service.

Fifth. The intermittent spouting of geysers is due to the gradual heating of water accumulated in fissures or tubes in the rocks, the only mechanism necessary being a tube, which may or may not have local expansions or chambers.

Sixth. Geysers may originate in several ways, though most commonly produced by the opening of new waterways along fissure planes of the rocks, by a gradual eating out of a tube by ascending hot vapors.

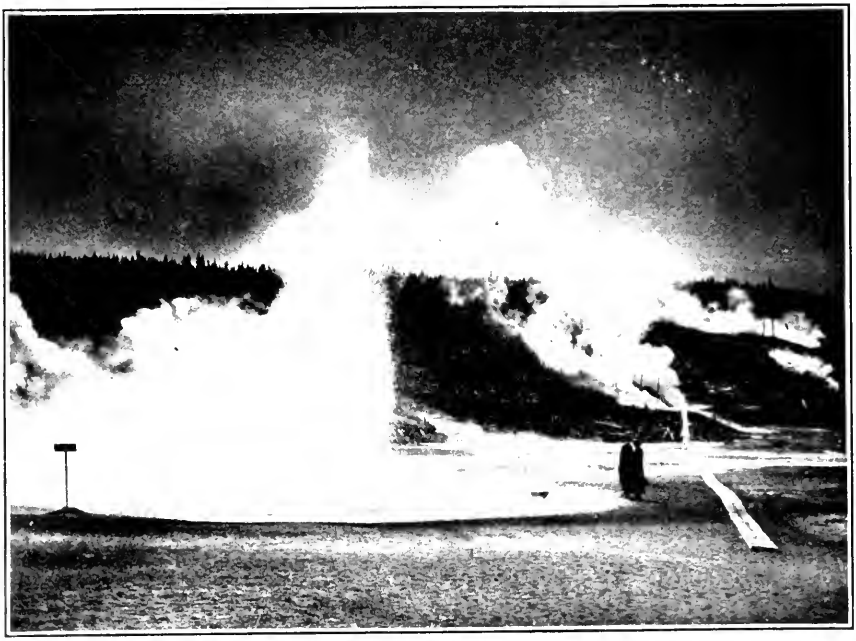
Seventh. The thermal activity of geyser regions is not rapidly dying out. The decrease of heat is very slow, and, though changes take place from year to year, the establishment of new geysers and new hot springs offsets the decay or drying up of old vents.

Attempts to solve the mysterious spouting of geysers date back to the earlier part of the present epoch of scientific research and the genius of Bunsen and Descloiseaux was devoted to a study of the Iceland geysers as early as 1847. The most important result of their experiments and observations was a theory of geyser action, now (with slight modifications) generally accepted, but other conclusions have been proven by observations made in the Yellowstone Park to be erroneous. Although numerous visits to the geysers of Iceland by later observers led to various ingenious speculations and theories respecting geyser eruptions, the questions of geyser origin and the significance of their occurrence and other questions of broader scope were not touched upon.

In looking at the distribution of geysers in various parts of the world, one is quickly impressed with their great rarity. Hot springs abound in many countries, but boiling springs are characteristic only of regions of recent (that is, geologically recent) volcanic activity; only in such regions do geysers occur. Until late in the last century Iceland was the only land where geysers had been found. Less than 60 years ago they were discovered in considerable numbers in New Zealand, and since then a few others have been reported from other parts of the world. The "Geyserland" of the world is undoubtedly, however, the Yellowstone National Park, a region situated in the heart of the Rocky Mountains, at the headwaters of the Missouri and Yellowstone.

In order to bring before the reader a general idea of the true relation of geyser vents to the surrounding topography and watercourses of the districts, a brief description of the great geyser regions of the world will be attempted. It has been my good fortune to have spent seven summers at the various geyser "basins" of the Yellowstone in connection with my duties as assistant geologist on the United States Geological Survey party under Arnold Hague. The other regions are familiar from a large series of excellent photographs, as well as through the descriptions of friends and the writings of other visitors to those countries.

New Crater Geyser, Norris Basin.
Photograph by F. J. Haynes.



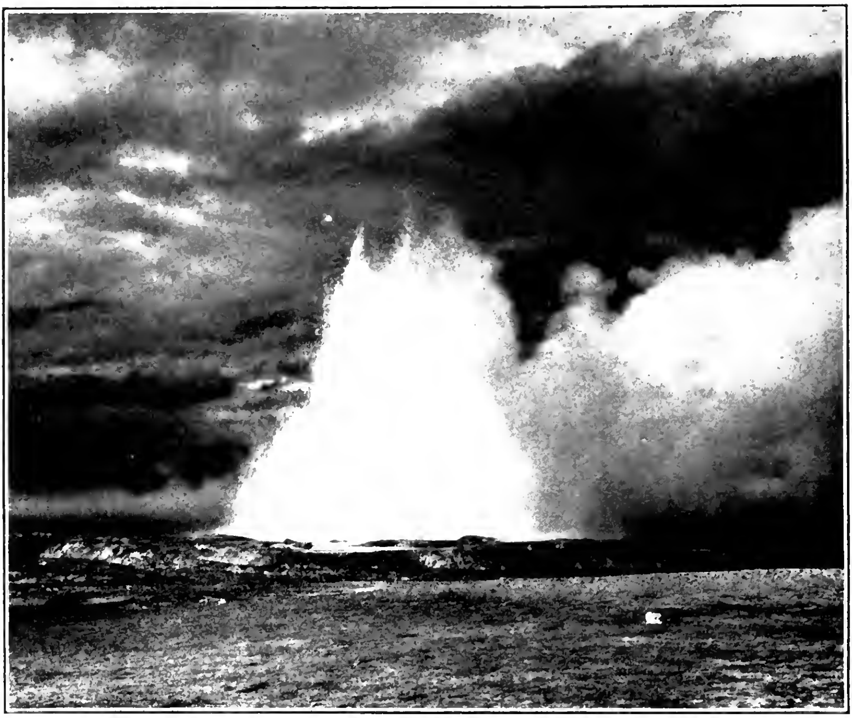
Constant Geyser, Norris Basin.
Photograph by F. J. Haynes.

THE ICELAND GEYSERS.

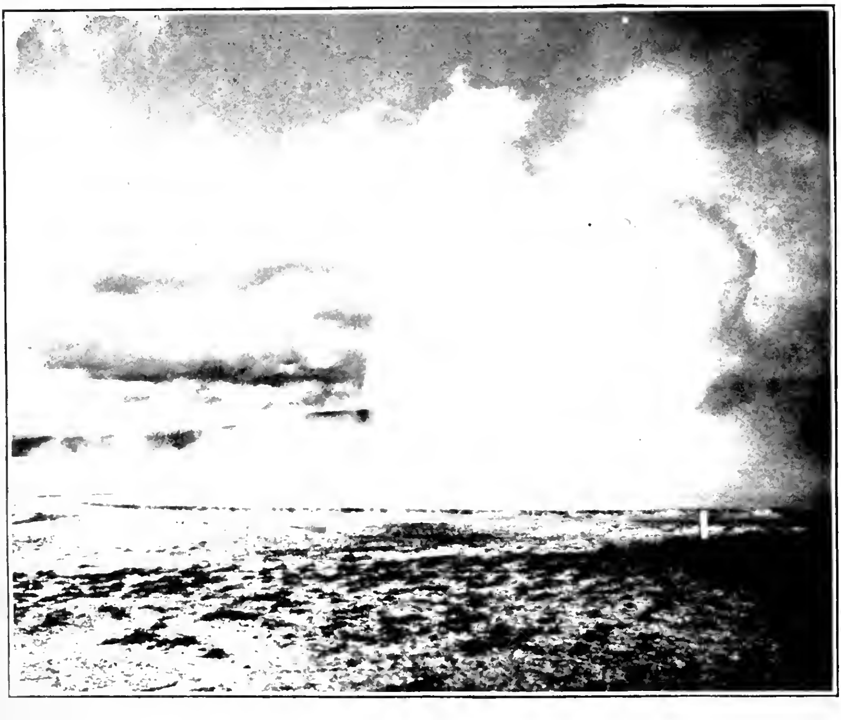
Iceland is the birthplace of the word geyser. It has been called the land of frost and fire, and indeed in no place are the evidences—nay, the very forces themselves—of frost and fire brought so forcibly in contrast. The island is eminently a volcanic region, a central table-land with sharp volcanic peaks, hooded with great Jökuls, or glaciers, mantled with perpetual snows, and surrounded by a more or less narrow strip of low-land bordering upon the sea. The evidences of internal fire are unmistakable. Hecla and other volcanoes are occasionally active, and the whole island is covered with lava poured out by the volcanoes, and the source of the heat supplying the geysers is unquestioned.

As would naturally be expected from the combination of water and fire, hot springs are abundant and at a few localities geysers are found. The most noteworthy of these is Haukadal, where The Geyser, Strokr, and a smaller geyser are found. This locality is about 70 miles from Reykiavik, the Iceland metropolis, and is only reached on horseback over beds of clinkers and rough lava fields; a dreary ride so far as scenery goes, but of fresh novelty to visitors from warmer lands. The hot springs are clustered in an area of about 20 acres, at the base of a hill about an eighth of a mile long and 300 feet high, and at the edge of the marshy bottom that stretches out toward the Hvita River. The springs are really at the base of the seaward border of the high ground, where the waters that have percolated through the tufas and porous lavas of the higher region would come to the surface. The two geysers Strokr and The Geyser issue from mounds of gray or white silica deposited by the hot waters, and the neighboring springs are surrounded by lesser areas of the same material, while on the hillside back of the springs the rock is decomposed by the steam of fumeroles. These two large spouters show two types of geysers. Strokr has a funnel-like pit 36 feet deep and 8 feet across (see page 25), expanding into a saucer-like basin. The tube is generally filled to within 6 feet of the top with clear water, which boils furiously, owing to the escape of great bubbles of steam coming from two openings in opposite sides of the tube. The eruptions are quite as beautiful as those of its more famous companion, the jets rising in a sheaf-like column to a height of 100 or more feet, eruptions taking place at very irregular and long intervals; but by putting a lid on this great kettle, by dumping in large pieces of turf, an eruption can be produced in a short time.

The Geyser, on the contrary, is a pool of limpid green water whose surface rises and falls in rhythmic pulsations. The usual temperature is but 170° F. or 200° F., but varies, being greater immediately before an eruption. The shallow saucer-like basin is about 60 feet across and slopes gently to a cylindrical shaft 10 feet in diameter, forming the pipe



Fountain Geyser, Lower Basin.
Photograph by F. J. Haynes.



Great Fountain Geyser, Lower Basin.
Photograph by F. J. Haynes.

of the geyser; this is about 70 feet deep. This regularity of the tube becomes important when we consider Bunsen's experiments and the theory of geyser action he deduced from them. Before an eruption bubbles of steam entering the tube suddenly collapse with loud but muffled reports and a disturbance of the quiet surface of the water. During this simmering, for such it is, the water rises in dome-like mounds over the pipe and overflows the basin, running down the terraced slope and wetting the cauliflower-like forms of sinter that adorn it.

The eruptions that so long puzzled and astonished visitors to this remote land are surpassed by those of the giants of the Yellowstone, but their beauty is not less. A short time before Geyser plays, the domes of water rising in the center of the basin come in quick succession and finally burst into spray, followed by a rapid succession of jets increasing in height until the column is 100 feet high. Dense clouds of steam momentarily hide the glistening sheaf of jets, hiding it from sight, then drifting away in the breeze again reveal the sparkling shaft.

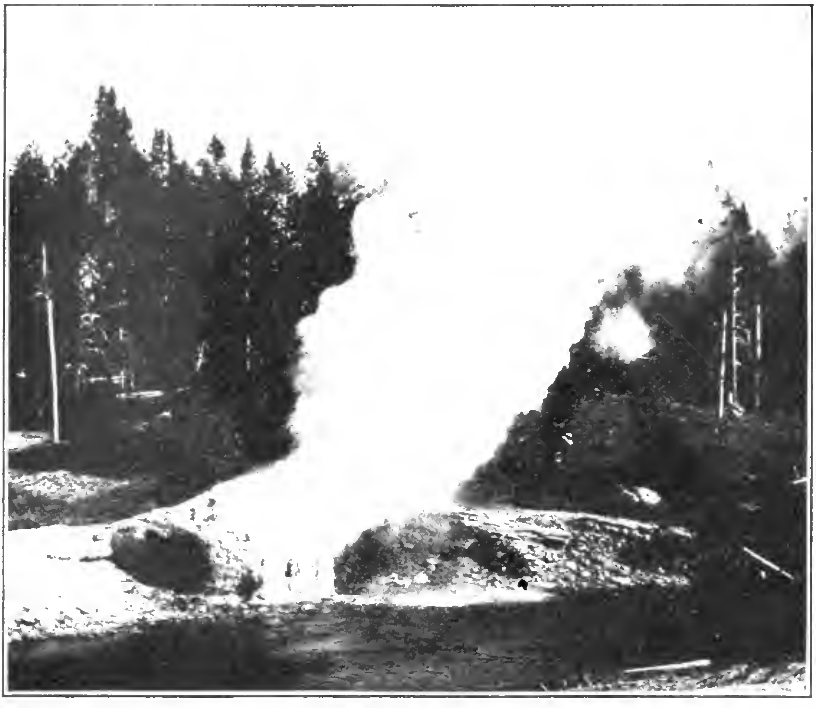
These eruptions have varied much in appearance and height since the geyser was first known. At present the column does not exceed 90 feet and the eruption lasts but a few moments. After it the basin is empty and seems to be lined with a smooth coating of white silica.

THE GEYSERS OF NEW ZEALAND.

The geysers of New Zealand are situated in a region clothed with a luxuriant vegetation that is in strong contrast to the bleak and barren lava fields of Iceland, but an examination of the position of the springs, with respect to the physical features of the region, shows that the situation of the geysers is nearly the same in these antipodal isles. The New Zealand geysers occur in the North Island, in what is known as the volcanic region, or the Taupo zone. Within an area of 4,725 square miles, in which none but volcanic rocks are found, there are six volcanoes and great numbers of solfataras, fumeroles, mud volcanoes and hot springs, and many geysers. The lavas are all of the acid type, mostly rhyolite, but are hidden by surface decomposition and an abundant vegetation, save upon the flanks of the peaks. The axial line of this zone running northeast is marked at each end by an active volcano and its course by a line of greatest hydrothermal activity, a sinuous line of hot springs following well-marked geographic features of river valleys, low plains, and lake margins, with higher country on either side rising to plateaus of 2,000 to 3,000 feet above the sea.

Little is known of the geysers on the shores of Lake Taupo or those on the banks of the Waikato River, but the famous terraces of Rotomahana, called the eighth wonder of the world by James Anthony Froude, attracted attention to the geysers which formed them, and made their

Grotto Geyser, Upper Basin.
Photograph by F. J. Haynes.



Riverside Geyser, Upper Basin.
Photograph by F. J. Haynes.

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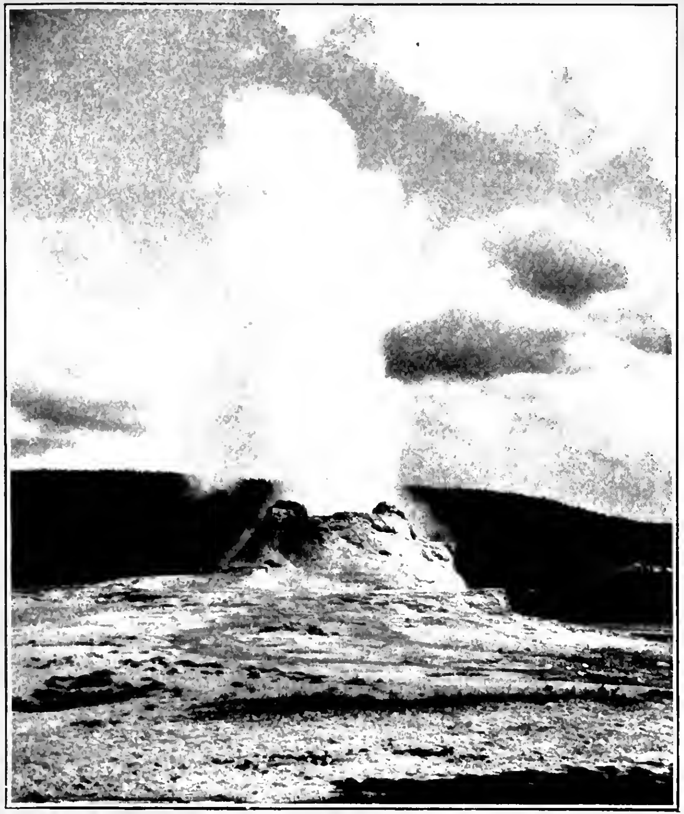
vicinity the best-known part of the district. The warm lake called Rotomahana by the Maoris was a shallow body of warm water about a mile long and a quarter of a mile broad, comprising 185 acres. The waters were of a dirty greenish hue, reflecting the somber green of the fern and the ti-tree-covered slopes about it, and the sedgy margins sheltered large numbers of duck and other water fowl. Rising above its surface like stairways of delicately sculptured marble were the pink and white terraces. At the top of the terrace, 120 feet above the lake, was the Terata Geyser, whose overflow had built up this wonderful work and filled the basins and pools with waters whose tints were both the delight of the eye and the despair of the pen.

The geyser caldron was some 60 by 80 feet across, its clear and boiling water usually overflowing and occasionally ejected to a height of 40 to 100 feet, wetting the steep banks of bright-colored fumerole clays about the crater but not forming the beaded geyserite characteristic of so many of these fountains. Such eruptions followed a period of quiescence, when the waters retired within the pipe for many hours. Owing to the comparative inaccessibility of the caldron and the beauty of the terraces, but few observations are on record of the action of the geyser. The water carried 150 grains of solid matter to the gallon, of which one-third was silica, and the daily outflow of 100,000 to 600,000 gallons per hour brought up 10 tons of solid matter dissolved out of the underlying rocks. It is easy to see what great underground caverns would be formed by this geyser alone in a comparatively brief time. In the volcanic outbreak of Tarawera, in June, 1886, the waters of the lake and underground reservoirs were drawn into the newly opened fissure, and, by the extraordinary explosion that followed, the terraces were destroyed and the site of Rotomahara became a crater that threw mud over the surrounding country.

THE YELLOWSTONE "GEYSERLAND."

The wonderful variety, the great number, and the large size of the geysers of America, found in the Yellowstone National Park, demand a somewhat longer account of this region. The geysers are found in detached groups, occupying basins or valleys of the great table-land which forms the central portion of the park, a region whose heavy forests and uninviting aspect, combined with the rugged nature of the encircling mountain ranges, so long proved a barrier to exploration, even to those adventurous trappers and prospectors of the Great West.

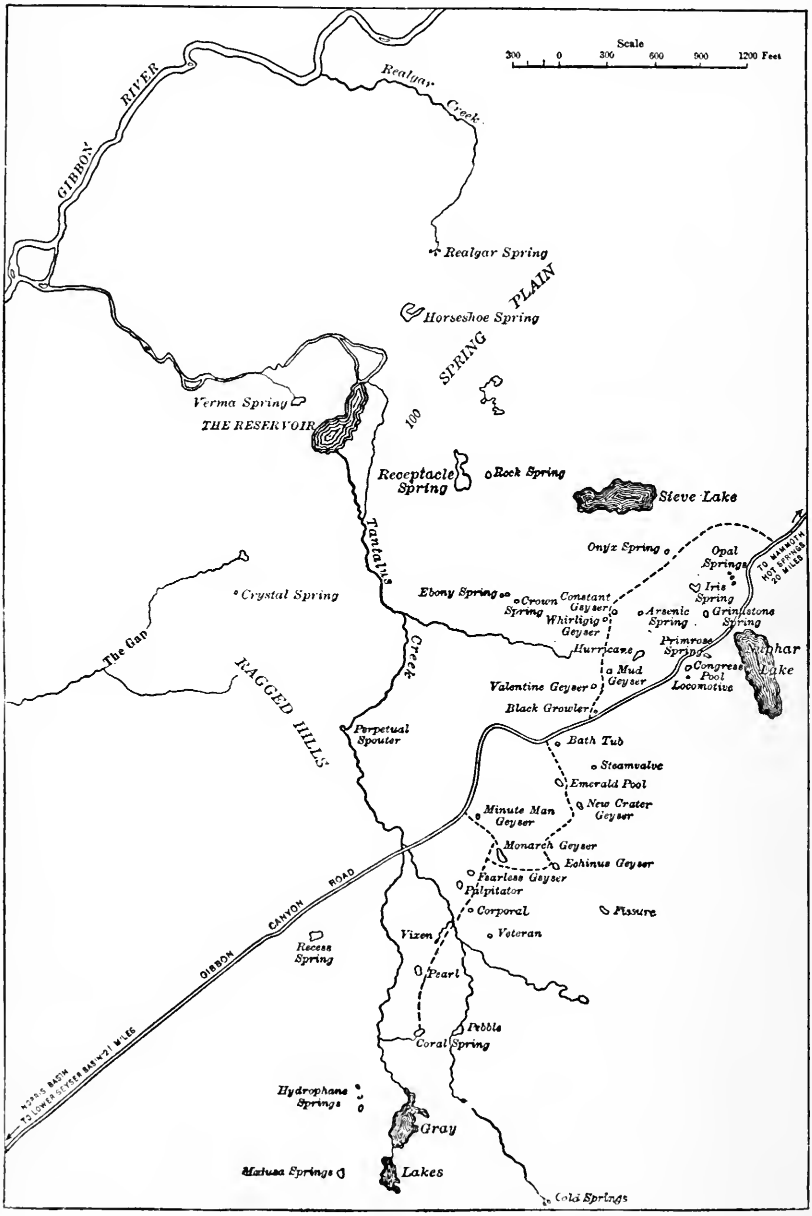
The geyser "basins," as the localities are termed, conform, in their relations to the surrounding high ground and their coincidence with lines of drainage and the loci of springs, to the laws governing the distribution of the same phenomena in other parts of the world. The park itself is a reservation of about 3,500 square miles, the central portion being an



Castle Geyser.
Photograph by F. J. Hayne

Giant Geyser.
Photograph by F. J. Haynes

elevated volcanic plateau, accentuated by deep and narrow canyons and broad, gentle eminences and surrounded by high and rugged mountain



Sketch Map of Norris Geyser Basin.

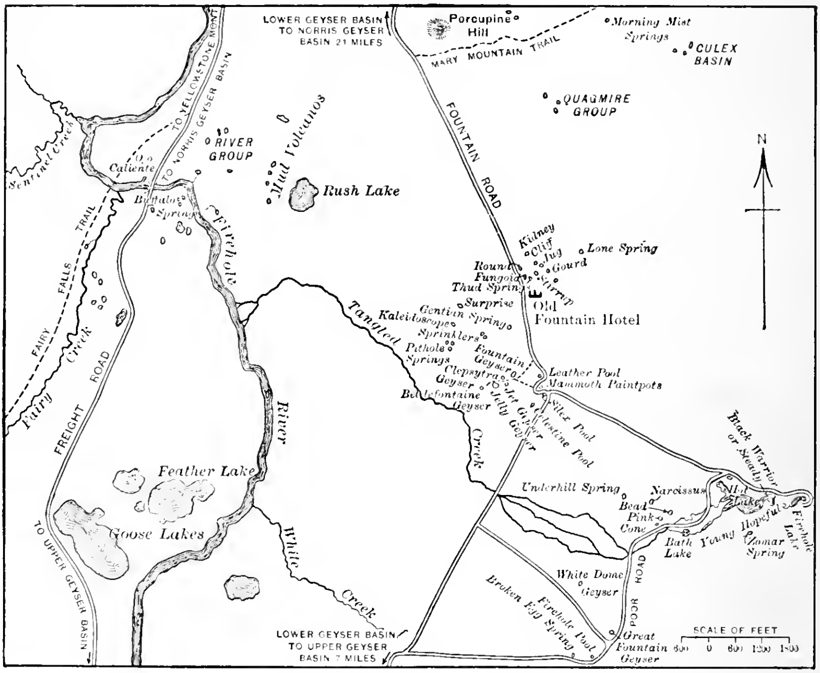
ranges. This central portion, whose average elevation is about 8,000 feet above the sea, embraces all the hot-spring and geyser areas of the park. The volcanic activity that resulted in the formation of the park

Sponge Geyser, Upper Basin.
Photograph by F. J. Haynes.

Economic Geyser,[1] Upper Basin.
Photograph by F. J. Haynes.

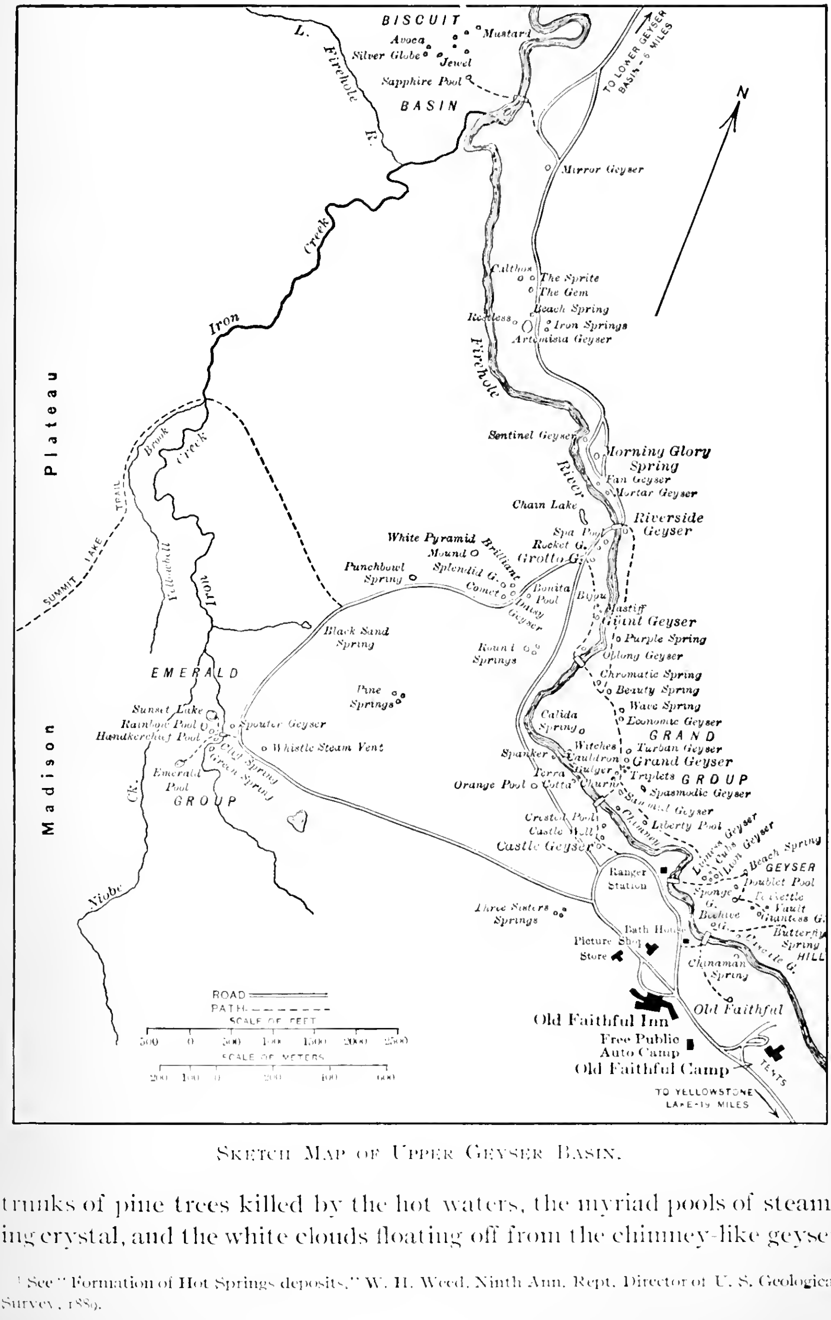
[1] No longer active.

plateau may be considered as extinct, nor are there any evidences of fresh lava flows. Yet the hot springs so widely distributed over the plateau are convincing evidence of the presence of underground heat. There is no doubt that the waters derive their high temperature from the heated rocks below, and that the origin of the heat is in some way associated with the source of volcanic energy.



SKETCH MAP OF LOWER GEYSER BASIN.

The various geyser basins, or "fire holes," as they were called by the first explorers, each possess individual peculiarities which give character and interest to each locality. The most noted of these basins is, however, that known as the Upper Geyser Basin of the Firehole River. one of the headwaters of the great Missouri. The Upper Basin, as it is generally called, lies a little westward of the center of the park. It is a valley 1½ miles long by one-half mile broad, inclosed by the rocky cliffs or darkly wooded slopes of the great Madison Plateau and drained by the Firehole River, along whose banks the largest geysers are situated, The whole floor of the valley is fairly riddled with springs of boiling water, whose exquisite beauty is indescribable. Light clouds of fleecy vapor curl gently upward from waters of the purest azure or the clearest of emerald, and, encircling rims of white marblelike silica, form fit setting for such great gems. A large part of the valley floor is covered with the white deposit of silica known as siliceous sinter, deposited by the overflowing hot waters.[1] The weird whiteness of these areas, the gaunt white



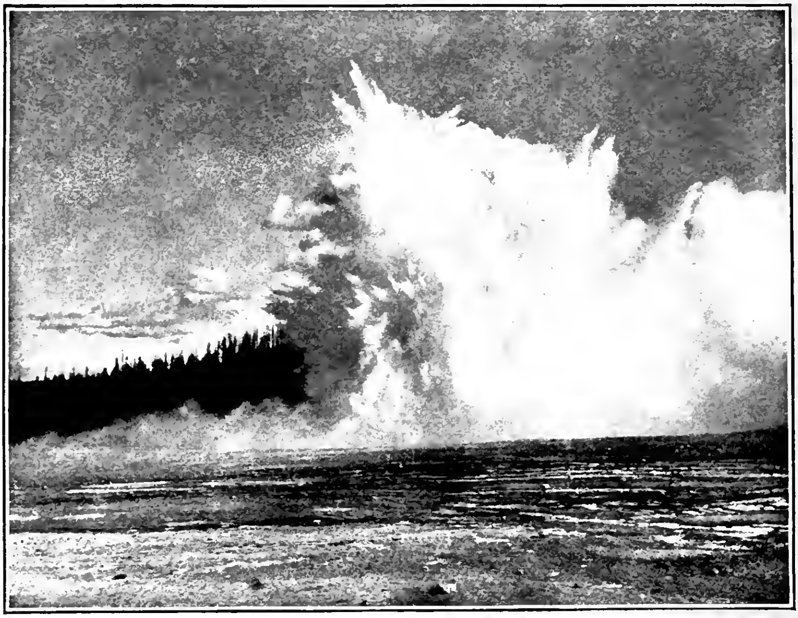
SKETCH MAP OF UPPER GEYSER BASIN.

trunks of pine trees killed by the hot waters, the myriad pools of steaming crystal, and the white clouds floating off from the chimney-like geyser

[1] See "Formation of Hot Springs deposits," W. H. Weed, Ninth Ann. Rept. Director of U. S. Geological Survey, 1889.

cones, form a scene never to be forgotten by those fortunate enough to behold it. Within this basin there are nearly 30 geysers, presenting many variations of bowl or basin, mound and cone, and whose eruptions are equally diversified in form and beauty.

Sentinel, Fan, Riverside, Mortar, and Grotto greet one on entering the basin either by quiet steaming or by flashing jets. Giant, Splendid, Castle, Grand, Giantess, Lion, and Old Faithful are but a few of the wondrous fountains of the place. The last is most deserving of its



EXCELSIOR GEYSER.[1]

Photograph by F. J. Haynes.

name. Ever since its discovery, in 1870, it has not failed to send up a graceful shower of jets at average intervals of 60 to 75 minutes. Its beauty is ever varying, as wind and sunlight play upon it, and the mound about its vent is adorned with delicately tinted basins of salmon, pink and yellow, filled with limpid water whose softness is enticing. It is the geyser of the park, and indeed of the world, and many a visitor to "geyserland" departs without seeing any other of the many spouters in action and yet feels more than repaid for the journey. For beauty of surroundings the Castle will perhaps be awarded the palm; its sinter chimney or cone is formed of exquisite cauliflower or coral-like geyserite, whose general form makes the geyser's name appropriate. Its eruptions are now irregular. A stream of hot water is thrown up to a height

[1] Ceased playing in 1888.

between 50 and 75 feet for about 30 minutes, followed by the emission of steam, with a loud roar that can be heard for miles.

The greatest geyser of the park, and indeed the grandest of the whole world, was Excelsior, some 25 miles beyond the Norris Basin. Unlike the less capricious and more fountain-like geysers of the Upper Firehole, this monster of geysers did not spout from a fissure in the rock, nor from a crater or cone of its own building. It was a monster of destruction, having torn out its great crater in the old sinter-covered slope, builded by the placid and beauteous Prismatic Lake. The walls, formed by the jagged ends of the white sinter layers, were lashed by the angry waters that were ever undermining the sides and enlarging the caldron. The eruptions were so stupendous that all other geysers are dwarfed by comparison. The grand outburst was preceded by several abortive attempts, when great domes of water rose in the center and burst into splashing masses 10 to 15 feet high, while the waters surged under the overhanging walls and overflowed the slope between the crater and the river. Finally, with a grand boom or report that shook the ground, an immense fan-shaped mass of water was thrown up to a height of 200 or more feet, great clouds of steam rolled off from the boiling water, while large blocks of the white sinter were flung far above the water and fell about the neighboring slopes. Unfortunately, this monarch of all geysers has ceased to erupt.

Everywhere, save at the Norris Basin of the Yellowstone Park, geyser vents are surrounded by cones, mounds, or platforms of white siliceous sinter, which, though built up into very beautiful forms, hides the true relation of the geyser vent to the fissures in the rocks, so that it has been generally believed, as stated by Tyndall,[1] that the hot springs built up tubes of siliceous rock, that made them geysers. That this is not true is shown by several great fountains at the Norris Basin, that spout directly from fissures in the solid rock, notably the Monarch, Tippecanoe, and Alcove geysers.

Prominent geysers and springs, based upon observations during season 1920.

NORRIS BASIN.

Name.	Height of eruption.	Duration of eruption.	Interval between eruptions.	Remarks.
	Feet.			
Black Growler				Steam vent only.
Constant	15–35	5 to 15 seconds	20 to 55 seconds	Quiescent in 1920.
Congress pool				Large boiling spring.
Echinus	30	3 minutes	45 to 50 minutes	
Emerald Pool				Beautiful hot spring.
Hurricane	6–8			Continuous.
Minute Man	8–15	15 to 30 seconds	1 to 3 minutes	Sometimes quiet for long periods.
Monarch	100–125	6 minutes	Irregular	
New Crater	6–25	1 to 4 minutes	2 to 5 minutes	
Valentine	60	15 to 60 minutes	Irregular	
Whirligig	10–15	10 seconds	do.	Near Constant Geyser.

[1] Heat as a mode of motion.

Prominent geysers and springs, based upon observations during season 1920—Continued.

LOWER BASIN.

Name.	Height of eruption.	Duration of eruption.	Interval between eruptions.	Remarks.
	Feet.			
Black Warrior		Continuous		Small, but interesting geysers.
White Dome	10	1 minute	40 to 60 minutes	
Clepsytra	10–40	Few seconds	3 minutes	
Fountain Geyser	75	10 minutes	2 hours	
Firehole Lake				Peculiar phenomena.
Great Fountain	75–150	45 to 60 minutes	8 to 12 hours	Spouts 4 or 5 times.
Mammoth Paint Pot				Basin of boiling clay.
Excelsior	200–300	About ½ hour		Ceased playing in 1888.
Prismatic Lake				Size about 250 by 400 feet; remarkable coloring.
Turquoise Spring				About 100 feet in diameter.

UPPER BASIN.

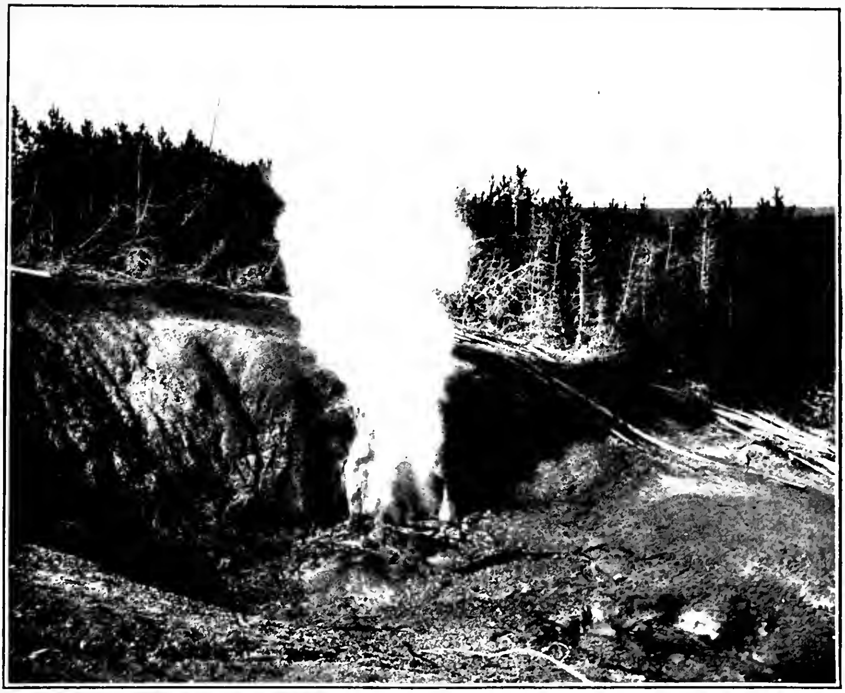
Name.	Height of eruption.	Duration of eruption.	Interval between eruptions.	Remarks.
Artemisia	50	10 to 15 minutes	24 to 30 hours	Varies.
Atomizer	2			
Beehive	200	6 to 8 minutes	3 to 5 times at 12-hour intervals following Giantess.	
Cascade				Quiet again.
Castle	50–75	30 minutes	Irregular	
Cub, large	60	8 minutes	With Lioness	Short chimneys to Lion and Lioness.
Cub, small	10–30	17 minutes	1 to 2 hours	
Daisy	70	3 minutes	80 to 90 minutes	
Economic	20	Few seconds		Seldom in eruption.
Fan	15–25	10 minutes	Irregular	
Giant	200–250	60 minutes	6 to 14 days	
Giantess	150–200	12 to 36 hours	Irregular, 5 to 10 days	
Grand	200	15 to 30 minutes	10 to 12 hours	
Grotto	20–30	Varies	2 to 5 hours	
Jewel	5–20	About 1 minute	5 minutes	
Lion	50–60	About 2 to 4 minutes	Irregular	Usually 2 to 17 times a day.
Lioness	80–100	About 10 minutes	do	Played once in 1910, once in 1912, once early in 1914, and once in 1920.
Mortar	30	4 to 6 minutes	do	
Oblong	20–40	7 minutes	8 to 15 hours	
Old Faithful	120–170	4 minutes	60 to 80 minutes	Usual interval 70 minutes.
Riverside	80–100	15 minutes	6 to 7 hours	Very regular.
Sawmill	20–35	1 to 3 hours	Irregular	Usually 5 to 8 times a day.
Spasmodic	4	20 to 60 minutes	do	Usually 1 to 4 times a day.
Splendid	200	10 minutes		Not played since 1892.
Sponge		1 minute	3 minutes	A small but perfect geyser.
Turban	20–40	10 minutes to 3 hours	Irregular	

Notable springs.—Black Sand Springs (about 55 by 60 feet), Chinaman, Emerald Pool, Morning Glory, Punch Bowl, Sponge, Sunset Lake.

GEYSER WATERS.

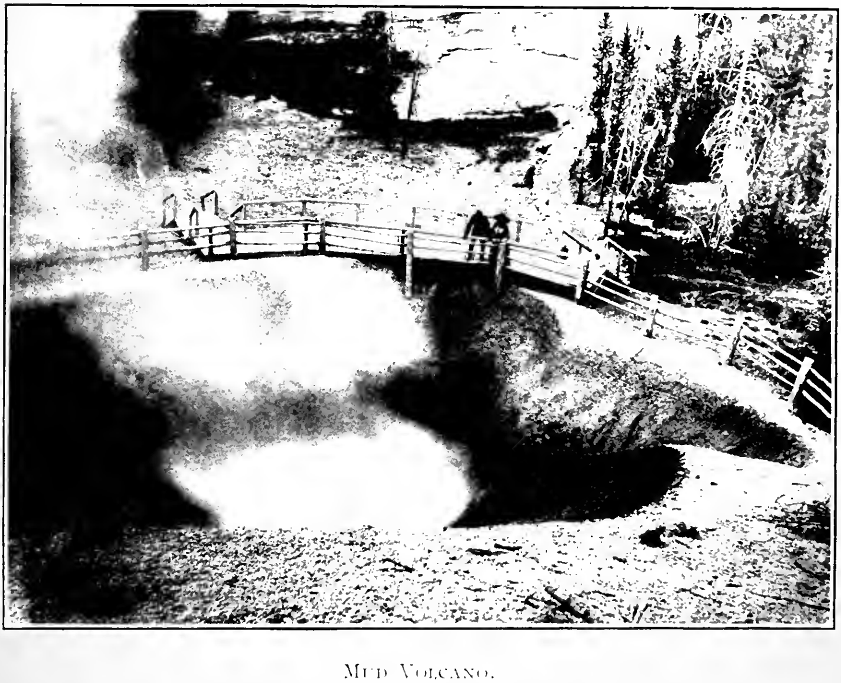
The descriptions which have been given of the chief geyser regions of the world lead to the question, What is the source and character of the geyser waters? It has been plainly indicated that in the fields described the vents are always situated along lines of drainage, on the shores of lakes, or under conditions where ordinary springs of meteoric water would naturally occur.

That the geyser waters are surface waters which have percolated through the porous lavas and have been heated by encountering great



Black Growler, Norris Basin.[1]

Photograph by F. J. Haynes.



Mud Volcano.

Photograph by F. J. Haynes.

[1] Present Black Growler, steam vent only.

quantities of steam and gases rising from the hot rocks below there is no reasonable doubt. The proximity of ordinary cold springs and those of boiling hot water lends support to this view.

These hot waters, traversing the rocks in irregular fissures, readily dissolve out the more soluble constituents of the rocks, the amount and the character of the salts present varying somewhat with the nature and amount of gases held in the waters. Chemical analyses of geyser waters from the three regions described show no greater variation than those from different vents in any one of these regions.

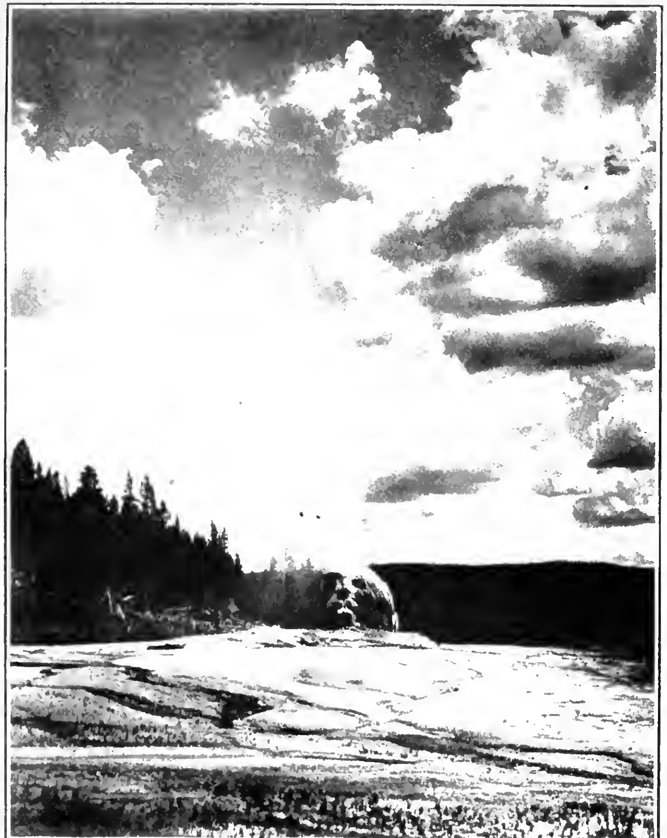
Source of heat.—That the source of steam is the still hot lavas below, and is in some way connected with volcanic action, is so evident from the facts that no other conclusion is possible. A very common belief concerning the source of the heat of boiling springs and geyers, but one which no longer has the support of scientific men, is that the heat results from chemical action, as it is vaguely termed. Were not the evidence so directly opposed to this idea, it would merit consideration, but so far as the heat of geyser waters is concerned all observation shows it to be untenable. To this class of theories belongs the popular idea that the geyser basins are underlain by great beds of (quick?) lime, which supply the heat and steam of the geysers.

The smothered combustion of beds of lignite, coal, or pyrites is another form of the same theory that has been received with considerable favor and still commands a few followers. That hot springs may have such an origin is not denied, but the geological conditions and environment clearly show that none of the great geyser regions of the world derive their heat from such action.

Where the source of supply is deep-seated, spring waters always have an elevated temperature, generally proportionate to the depth, but the very high temperatures of the geysers and the local source of the waters exclude this theory. The folding and faulting of rocks is another source of heat made manifest by hot springs.

It has been shown by Dr. Peale, however, that boiling waters are only found in the regions of volcanic rocks, and it was pointed out by L'Apparent that geysers only occur in acid volcanic lavas. In Iceland the volcanic forces are still active, and melted lavas may exist at no great depth. In New Zealand the recent eruption of the eroded mountain Tarawera showed that heated rocks exist and in that case rose up near enough to the surface to cause the explosion which so transformed the country.

In the Yellowstone there are no active volcanoes, and none of even geologically recent activity. The lavas that fill the ancient mountain-encircled basin of the park are scored by glaciers and deeply cut by running water, and the old volcanoes from which the lavas were, in part at least, outpoured show no signs of having been active since Tertiary times. Yet in this region the expenditure of heat by the hot springs,



Lone Star Geyser.
Photograph by F. J. Haynes.

Beehive Geyser, Upper Basin.
Photograph by F. J. Haynes.

geysers, and steam vents would undoubtedly keep a moderate-sized volcano in a very active state were it concentrated. There is no doubt that this heat is connected with the past volcanic energies of the region and derived principally from the still hot lavas, three-quarters of the entire area of the park (3,500 square miles) being covered by rhyolitic rocks.

The significance alluded to above, of the association of geysers and acid lavas (rhyolites), is possibly to be found in the fact that these rocks are more easily dissolved by the hot waters forming the tubes and reservoirs for geysers. The situation of hot springs and geysers along water-courses has already been mentioned. It is a well-known fact that the presence of water in the pores of a rock increases its capacity to conduct heat, so that we may surmise a rise in the local isogeotherm in such situations.

Geyser eruptions.—Geysers have often been compared to volcanoes, presenting in miniature, with water instead of molten rock, all the phenomena of a volcanic eruption. The diversity of form and varying conditions of activity of the hot springs found associated with geysers makes it impossible to determine in every case whether a spring is or is not a geyser. Geyser vents may be mere rifts in the naked rocks or bowls of clear and tranquil water, quiet until disturbed by the first throes of an eruption, and surrounded by white sinter deposits in nowise distinguishable from those about hot springs. In other cases the vents are surrounded by a cone or mound of pearly beaded "geyserite," a certain and distinctive feature of a geyser.

The displays of the great "Geyser" of Iceland have already been briefly described; they may be taken as the type of eruptions from geysers having bowl-like expansions at the top of the tube, the so-called "basin" of the geyser. Where the vent is surrounded by a cone of sinter, as is so often the case among the fountains of New Zealand and the Yellowstone, the first part of the geyser eruption is somewhat different. Perhaps the most familiar geyser of this type is Old Faithful, the one geyser in the Yellowstone that is sure not to disappoint the visitor. Though surpassed by many of its neighbors in the height and magnitude of its eruptions, it holds a front rank for beauty and gracefulness. Previously heralded by loud rumblings, with spasmodic outbursts of 10 to 20 feet in height that mark abortive attempts to send up its steaming pillar, the white column is finally thrown upward with a loud roar, and mounts at once to a height that seems hundreds of feet as we gaze upon it. For one or even two minutes the column maintains a height which measurements show to vary from 90 feet up to 150 feet, with occasional steeple-shaped jets rising still higher, the jets ever varying and giving off great rolling clouds of steam; then the jets gradually decrease in altitude, and in five minutes the eruption is over, the tube apparently empty, and emitting occasional puffs of steam for a few minutes longer.

Splendid Geyser.[1]
Photograph by F. J. Haynes.

Old Faithful Geyser.
Photograph by F. J. Haynes.

[1] Has not played since 1892.

During the eruption the water falls in heavy masses about the vent, filling the basins that adorn the mound, and flowing off in yellow and orange-colored waterways, while the finer spray drifts off with the breeze and falls upon the neighboring sinter slopes. It is impossible to measure the amount of water thrown out, since it runs off in a number of directions in shallow rills that lead either to the sandy terrace near by or to the river. If, however, we assume that the column of steam and water is one-third water, a fair assumption, the estimated discharge is 200,000 gallons at each eruption.

Comparing Old Faithful with its Iceland prototype we find considerable difference in the behavior of the two vents during the interval between eruptions. The former, like Strokr, has no bowl or basin, and the geyser throat or tube is partly filled with water, which is in constant and energetic ebullition while the geyser is inactive. The tube and bowl of "Geyser" are, on the contrary, filled with comparatively cool water. In each case, however, the eruption is preceded by an overflow from the geyser tube, in the case of Strokr and Old Faithful as jets of 10 feet to 25 feet in height; in "Geyser" by a filling of the bowl and successive overflows, accompanied by the noise of condensing steam bubbles, a simmering of the water in the tube. Such preliminary actions are significant when we consider the theory of geyser action.

It is unnecessary to describe the numerous other theories of geyser action; they all suppose caverns or systems of chambers and tubes, of definite arrangement, a supposition most unlikely to occur in many cases, and made unnecessary by Bunsen's theory. Local expansions and irregularities of the tube do exist, and to them we owe many of the individual peculiarities of geysers, but such chambers do not form a vital, essential part of the geyser mechanism.

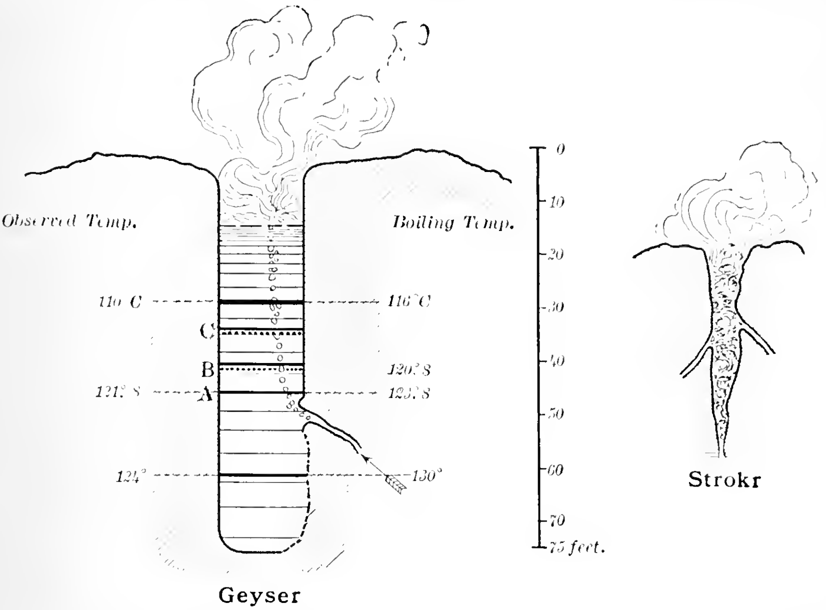
In an excellent résumé of the various theories of geyser action, Dr. A. C. Peale states that he believes no one theory is adequate to explain all the phenomena of geyser action, though Bunsen's theory comes nearest to it.[1]

Where the tube is surrounded at the top by a basin no actual overflow need occur. Indeed there is in the Yellowstone a miniature geyser, aptly named the Model, with a tube but 2 inches in diameter, surrounded by a shallow, saucerlike basin, which has eruptions about every 15 minutes of 3 feet to 5 feet in height in which scarcely a drop of water is wasted, but flows back into the tube after the eruption. During the interval between eruptions no water can be seen in the tube, whose basin and upper part are dry and cool. The first signal of the coming display is a quiet welling up of the water in the tube filling the little basin, which being relatively large and shallow relieves the water column of a considerable height. During the eruption which follows, the spray is chilled by the air, falling back into the basin; at the end of the display the water is quickly sucked back into the tube and reheated for the ensuing eruption.

[1] Twelfth Ann. Rept. U. S. Geol. and Geog. Survey Territories, vol. II., p. 422.

At first thought the constant boiling of the waters in the tube of Strokr, Old Faithful, and many other geysers seems to oppose the theory which we have just given. Observations show however that in many cases the boiling is confined to the surface and deep temperatures do not reach the boiling point corresponding to the depth. It is quite likely also that in some cases a lesser and independent supply of heat may connect with the upper part of a geyser tube; Strokr, we know, has two vents (see figure), one of which is the geyser tube, the funnellike throat of Strokr being really but a nozzle to the geyser.

Theories of geyser action.—The intermittent spouting of geysers was long a riddle to scientific men, for although several theories seemed each



Sections of Geyser and Strokr Showing Fissures Supplying Geyser Tubes (After Campbell).

to offer a satisfactory explanation of the eruptions of "Geyser," they supposed conditions unlikely to occur in many vents. The investigations of Bunsen, and of Descloizeaux, who spent two weeks studying the Iceland fountains, resulted in the announcement of a theory of geyser action which, with slight modifications, has satisfied all requirements and is to-day generally accepted as the true explanation of the action of these natural steam engines. This theory, which bears the name of the illustrious Bunsen, depends upon the well-known fact that the boiling point of water rises with the pressure, and is therefore higher at the bottom of a tube of water than at the surface. The temperature of water heated in any vessel is generally equalized by convective currents, but in a long and narrow or an irregular tube this circulation is impeded, and while the water at the surface boils at 100° C. (at sea level), ebullition in the lower part of the tube is only possible at a much higher temperature, owing to the weight of the water column above it. In the section of Geyser shown in the figure the observed temperatures are given on the left, and the temperatures at which the waters would boil, taking into account the pressure of the water column, are given on the right. In Geyser the nearest approach to the boiling point is at a depth of 45 feet opposite a ledge and fissure discovered subsequent to Bunsen's experiments. At this depth the temperature is 2° C. below the temperature at which the water can boil. If by the continued heating of this layer by steam from the fissure it attains the temperature at which it can boil, steam is formed, whose expansive force lifts the superincumbent column of water, causing a slight overflow at the top, which, shortening the column, brings the layer B to the position C, where its temperature is above the boiling point of C, wherefore steam is formed at this point and a further lifting and relief of pressure ensues, followed by an eruption.

In illustration of this theory a model geyser is easily constructed of a glass tube an inch or so in diameter and several feet long. When this tube is closed at one end, filled with water and placed upright we have all the mechanism necessary to produce all the phenomena of a geyser. By heating the water at the bottom by the introduction of steam (or with a spirit lamp), we can produce eruptions whose period will depend upon the intensity of the heat. At first the bubbles of steam collapse in the cool waters at the bottom of the tube, but as the temperature rises the bubbles rise part way up the tube and heat the lower part of the column to a high temperature while the water near the surface is still cool. Eventually the water at the bottom reaches the pressure boiling point, when steam is formed, lifting the water above it and causing an overflow at the top. This overflow or its equivalent, the filling of a shallow basin at the top of the tube relieves the pressure and all that part of the column whose temperature was previously below the boiling point but now exceeds it, flies into steam and ejects the water above with great violence. The glass walls of our geyser tube permit us to watch the gradual heating of the water by means of thermometers suspended in the tube, the ascent and collapse of steam bubbles, the overflow and abortive attempts to erupt and the final ejection of the water from the tube.

I believe, however, that Bunsen's theory is a perfect explanation if we but admit that the geyser tube may be neither straight nor regular, but of any shape or size, and probably differing very much for each vent. The shape of the bowl or basin exercises but little influence upon the eruption save to produce the many individual peculiarities of the geyser column.

Origin of geysers.—It should be noted that Bunsen's theory of geyser action is quite independent of his theory of geyser formation. The building up of a siliceous tube by the evaporation of the waters at the margin of a hot spring is a process which may be seen in operation in any of the geyser regions of the world; but it is not a necessary pre lude to the formation of a geyser, for a simple fissure in the rock answers equally well, as is shown at the Norris geyser basin in the Yellowstone Park.

The life history of a geyser varies, of course, for each one, but observations show that the following sequence of events often takes place. The hot vapors rising from unknown depths penetrate the rocks along planes of fracture and shrinkage cracks, decomposing and softening the rock until the pressure of the steam and water is sufficient to force an opening to the surface. If this opening affords an easier exit for waters issuing at a higher level, the fissure is probably opened with a violent ejection of mud and débris; more often the process is a gradual one, accompanying the slow eating away of the rock walls along the fissure. The flowing waters slowly clear out the fissure, forming a tube that permits the freer escape of hot water and steam, while at the same time the waters change from a thick mud to a more or less clear fluid. The spring, at first a simple boiling mudhole, is now an intermittently boiling spring, which soon develops true geyser action. If the opening of the fissure afforded a new outlet for the waters of some already existing geyser, these changes take place rapidly, and eruptions begin as soon as the pipe is sufficiently cleared to hold enough water. The bare rock about the vent or fissure is soon whitened by silica deposited by the hot waters. This sinter may form a mound about the expanded tube or basin, or, if the vent shall be smal' and spray is frequently ejected, it builds up the curious geyser cones so prominent in the Yellowstone. In certain cases the building up of these deposits may partially choke the geyser's throat and cause a diminution of the geyser's energy, whose forces seek an easier outlet. In other cases the eating out of new subterranean waterways deprives the geyser of its supply of heat, and the vent becomes either tranquil or wholly extinct, while the pearly geyserite forming its cone disintegrates and crumbles into fine shaly débris, resembling comminuted oyster shells. Thus there is a slow but continual change in progress at the geyser basins, in which old springs become extinct and new ones come into being and activity.

With few exceptions, where the vents are very new, geysers spout from basins or from cones of white siliceous sinter, or geyserite, deposited about the vent by the hot waters. Such deposits are formed very slowly, one-twentieth of an inch a year being an average rate of growth for the deposit formed by evaporation alone. These deposits of sinter are therefore an index to the age of the geyser. In many cases these sinter cones are very odd, fantastic structures of great beauty while wet by the geyser spray, but becoming white, opaque, and chalk-like upon drying. Where the spattered drops fall in a fine spray the deposit is pearly and the surface very finely spicular. If the spray be coarse, the rods are stouter and capped by pearly heads of lustrous brilliancy. Thus the cone is not only a measure of a geyser's age and activity, but it tells, in a way, the nature of the eruption.

PUBLICATIONS ON YELLOWSTONE NATIONAL PARK.

DISTRIBUTED FREE BY THE NATIONAL PARK SERVICE.

The following publication may be obtained free on written application to the Director of the National Park Service:

Rules and Regulations, Yellowstone National Park (issued yearly). This pamphlet contains general information of interest to the tourist.

SOLD BY THE SUPERINTENDENT OF DOCUMENTS.[1]

The following publications may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at the prices given. Remittances should be made by money order or in cash:

National Parks Portfolio, by Robert Sterling Yard. 260 pages, including 270 illustrations. Bound securely in cloth, one dollar.

Contains nine chapters, each descriptive of a national park and one larger chapter devoted to other national parks and monuments.

Geological History of Yellowstone National Park, by Arnold Hague, 22 pages, including 10 illustrations, 10 cents.

This pamphlet contains a general résumé of the geologic forces that have been active in the Yellowstone National Park.

Geysers of the Yellowstone National Park, by Walter Harvey Weed, 32 pages, including 23 illustrations, 10 cents. (This publication.)

In this pamphlet is a description of the forces which have produced the geysers, and the geysers of the Yellowstone are compared with those in Iceland and New Zealand.

Fossil Forests of the Yellowstone National Park, by F. H. Knowlton, 32 pages, including 15 illustrations, 10 cents.

This pamphlet contains descriptions of the fossil forests of the Yellowstone National Park and an account of their origin.

Fishes of the Yellowstone National Park, by W. C. Kendall (Bureau of Fisheries Document 818). 28 pages, including 17 illustrations, 5 cents.

Contains descriptions of the species and lists of streams where found.

MAP.[1]

A topographic map of the park may be purchased from the Director of the Geological Survey, Washington, D. C., at the price given. Remittances should be made by cash or money order.

Map of Yellowstone National Park, size 28½ by 32 inches; scale, 2 miles to the inch. Price, 25 cents.

The roads, trails, and names are put in black, the streams and lakes in blue, and the relief is indicated by brown contour lines.

[1] May be purchased by personal application at the Information Office in the park, at Mammoth Hot Springs, but that office can not fill mail orders.

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